24
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Multislice Imaging of Integrated Circuits by X-ray Ptychography

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X-ray ptychography is a scanning type of coherent X-ray diffraction imaging based on iterative phase retrieval of multiple diffraction patterns, and provides internal information of a sample at a high spatial resolution potentially better than 10 nm. X-ray ptychography combined with computed tomography realizes high-resolution three-dimensional (3D) images. So far, a 3D resolution better than 20 nm has been achieved [1]. Recently, the high-resolution imaging of large-volume samples has been required. The projection approximation is an important factor that limits both the spatial resolution and maximum thickness of the sample. The relationship between the sample thickness and the achievable spatial resolution is described as [2]

$$T < 5.2 d_{x,y}^2 / \lambda,$$

where T is the sample thickness, $d_{x,y}$ is the resolution perpendicular to the propagation direction, and λ is the X-ray wavelength. To eliminate this limitation, a new phase retrieval algorithm using a multislice approach (3D Ptychographical Iterative Engine; 3PIE) has been proposed and demonstrated in the visible-light [3] and X-ray regimes [4]. The multislice approach describes a sample as multiple sections perpendicular to the propagation direction and calculates the wave propagation within the sample. So far, multislice X-ray ptychography has been applied to samples composed of discrete layers with a gap of larger than 10 μm [5]. In this study, we used multislice X-ray ptychography for the multisection observation of realistic integrated circuits.

X-ray ptychographic measurements were performed at BL29XUL in SPring-8. The two-layered TEG sample was composed of two circuits stacked with a ~1.4 μm distance on a Si substrate. The bottom Si layer was thinned to 20–30 μm by dry etching. A monochromatic 6.5 keV X-ray beam was two-dimensionally focused to a ~500 nm spot size by Kirkpatrick–Baez (KB) mirror optics. The sample was scanned over 10 × 10 raster grid with a step size of 300 nm. To collect high-frequency information in the horizontal and vertical direction, ptychographic diffraction data sets were recorded at nine angles, (φ,ω)=(0°, 0°), (1°, 0°), (-1°, 0°), (0°, 1°), (0°, -1°), (1°, 1°), (1°, -1°), (-1°, 1°), (-1°, -1°), where φ and ω are the horizontal and vertical tilt angles, respectively. Figure 1 shows the phase image of the first and second layer of the two-layered object reconstructed by precession 3PIE [5] from nine diffraction pattern sets, and the merged images of these reconstructions. The structures of Cu wiring on each layer were clearly reconstructed and the translational shift between the first and second layers was ~ 30 nm in both the horizontal and vertical directions. For the sake of comparison, a 3D image of the sample, whose voxel size was isotropic, was reconstructed from the projection images at each angle by the filtered back-projection method, in which the projections were reconstructed by using ePIE [6]. The 3D image was divided into two equal parts along the propagation direction. It was difficult to evaluate the positional shift owing to the appearance of artifacts expected from thickness effect of the sample and filtered back projection reconstructions with a low number of projections and a large missing wedge. These results indicated that the use of precession 3PIE reduces the appearance of artifacts and provides more precise images.

In this study, we have demonstrated a method for nondestructively multisection imaging of integrated circuits by X-ray ptychography with a multislice approach. We measured ptychographic diffraction intensities scattered from a two-layered object with a gap of 1.4um at nine angles, and precession 3PIE was applied to them. Each slice was successfully reconstructed and we found that layers were shifted by approximately 30 nm in the horizontal and vertical direction [7]. In this presentation, the experimental results of multisection observation of an Intel CPU will be shown.

References:

[1] M. Holler *et al.*, Nature **543** (2017) 402.
[2] E. H. R. Tsai *et al.*, Opt. Express **24** (2016) 29089.
[3] A. M. Maiden *et al.*, J. Opt. Soc. Am. A **29** (2012) 1606.
[4] A. Suzuki *et al*, Phys. Rev. Lett. **112** (2014) 053903.
[5] K. Shimomura *et al.*, Phys. Rev. B **91** (2015) 214114.
[6] A. M. Maiden *et al.*, Ultramicroscopy **109** (2009) 214114.
[7] K. Shimomura *et al.*, Acta Crystallogr. A **74** (2018) 66.

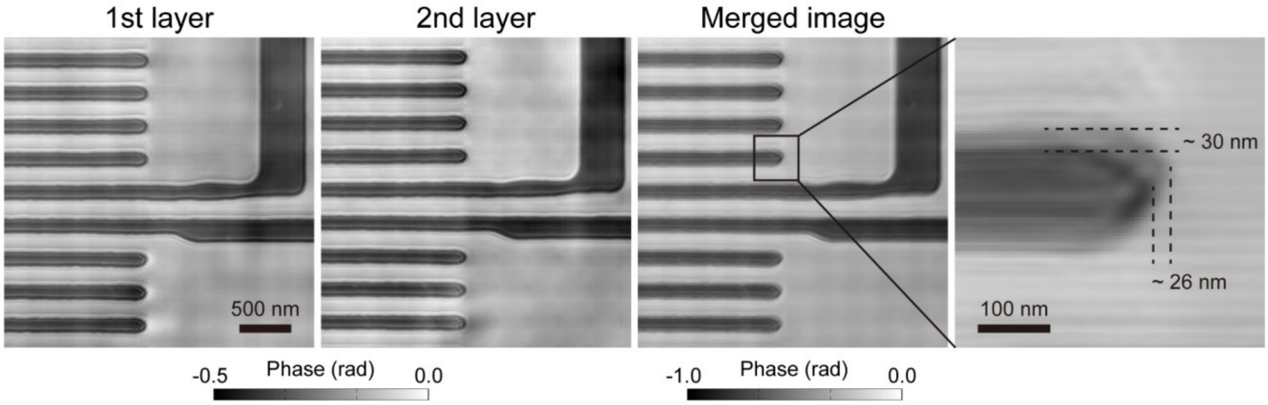

Figure. 1. Reconstructed phase images of the two-layered circuit, merged image, and the enlarged view of merged image. The positional shift between the first and second layers are 30 nm in the vertical direction and 26 nm in the horizontal direction.